PROPAGATION OF JOJOBA, _SIMMONDSIA CHINENSIS_, BY A MODIFIED SEED GRAFTING TECHNIQUE AND THE EFFECTS OF LIMING ON THE GROWTH AND NUTRIENT UPTAKE OF JOJOBA SEEDLINGS IN A SOILLESS MEDIUM

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I. INTRODUCTION

Jojoba, *Simmondsia chinensis* (Link) Schneider, is an evergreen dioecious shrub native to the Sonoran Desert (20). Over the last few years interest in the plant has increased rapidly due to the extraordinary liquid wax stored within the cotyledons of the seed. The high quality liquid wax, sometimes referred to as an oil, has physical and chemical properties similar to and, in some respects, superior to that of sperm whale oil (40).

Sperm whale oil is considered by some to be one of the finest lubricants in the world but its source is rapidly becoming extinct. Government restrictions have prevented the importation of sperm whale oil into the United States and the stockpile is dwindling. Hopefully a suitable substitute such as jojoba can be developed into an industry before the supply is exhausted.

The liquid wax of jojoba, which is unique to the plant kingdom, could also become a source of straight chain, monounsaturated alcohols and acids of which no other is readily available (40). The list of potential uses for jojoba oil is endless. At present most of the jojoba oil and seeds come from wild populations in the Sonoran Desert. Plantings established in various parts of the world over the last few years will soon come into production. At that time a feasibility study on cost of production, yields of seed and wax, market demand and price can be undertaken.

The drought and saline resistant shrub occupies a variety of different habitats within the state of California alone. One can find it growing under harsh desert conditions with an average annual rainfall of 8.75 cm and temperatures ranging from -6° to 60°C. On the other extreme, it is found close to the high tide line of the Pacific Ocean (56). Its ability to tolerate these harsh environments should not be taken as examples of ideal conditions for jojoba, since it grows productively in a variety of different areas under a wide range of conditions in many parts of the world; including Israel, Australia, Costa Rica, Hawaii and India. Since cultivation of the plant is new, many questions need to be answered before the ideal location for growing jojoba is known.

Many other facets of production, besides site selection, must be explored before jojoba becomes a viable industry. One very important prerequisite to domestication is that of propagation. Therefore, this paper will explore the various vegetative propagation techniques used with jojoba and test yet a new method. It will also concern itself with the effect of soil pH or lime on the growth and nutrient uptake of new jojoba seedlings in a soilless medium.

Literature Review

Jojoba is a woody shrub that is often multi-stemmed. In the wild it commonly grows between 1 - 3 meters tall, although larger plants can be found. Basically the plant is dioecious although a monoecious plant was recently discovered. It is primarily wind pollinated since the female flowers lack nectaries and do not attract insects. Therefore, synchronous flowering patterns of both sexes are important. Besides producing seed, the plant is useful in landscape either as a drought resistant hedge or as a specimen planting. In the wild it is an important browse species due to the high carbohydrate content of the leaves (16,19,20,41,51,54,56,58).

Since jojoba propagates very easily by seed, this method was the first employed in early attempts at domestication and today, with the lack of superior cultivars, this method is still widely used. However, for jojoba to become a viable industry, a means of vegetative propagation must be employed to avoid the highly heterozygous population that is obtained with seed propagation. As with other open pollinated fruit and nut crops, vegetative propagation is important to perpetuate a desirable clone or variety or to establish a new selection or hybrid.

Since jojoba is a wind pollinated dioecious plant, vegetative propagation has other advantages in that it allows for the selection of synchronous flowering male and female plants and also the adoption of a predetermined planting plan. Vegetative propagation techniques that have proven successful with jojoba include rooted cuttings (1,18,24,25,33,36), tissue culture (9,48,53,55) and grafting (27,54,56).

Vegetative propagation by tip cuttings treated with a rooting compound is a widely used technique for producing roots in a short time when treated cuttings are placed under mist. The percentage of success varies from zero to one-hundred percent and further testing is needed to determine if this variability is due to the genetic makeup of the mother plant or to the environmental conditions under which it is growing or being propagated. Other problems experienced in cutting propagation are: the occurrence of stem and leaf diseases promoted by the high humidity of the mist system; the lack of cutting material found on desirable high yielding mother plants; the fragility of the newly formed root system; the possibility of plagiotropism in cuttings taken from lateral branches; and the slowness of growth in the early stages of development (1,24,25,33,36).

Tissue culture techniques have been developed whereby complete plantlets were regenerated from shoot tip explants in a three-step procedure (48). This technique required that the elongated shoot be wounded to promote root formation which is highly consumptive of time and labor. Other authors have reported success in complete plantlet regeneration, however, their techniques were never published (9,55). Therefore, at present, propagation of jojoba by tissue culture is still in the experimental stage and is not used for commercial planting. This technique has promise of producing a large number of genetically uniform plants from a small amount of plant material and, if the plants can be economically produced, it will undoubtedly be an efficient method of propagation for that purpose.

Grafting of jojoba by the splice (54) and V-graft (56) methods have been used in the field to topwork undesirable plants and to establish male branches on female plants for pollination purposes. Splice grafting one to two year old wood (6 - 12 mm in diameter) with bark which has turned grayish-brown gave the best results whereas V-grafting one year old terminal wood with two to four nodes was recommended. Immature green wood has given poor results. The splice grafting technique reported success rates from 0 - 100 percent. Another reported problem with topworking was the profuse suckering that occurred on the rootstock below the graft union.

In the nursery, the practice of grafting has been secondary to other techniques. This is possibly due to: the ease of cutting propagation, the time and labor factors involved in producing a graftable seedling by the present grafting techniques, or the fear that the vigorous branching below the graft union may be difficult to control.

Propagation by grafting is used extensively in many fruit and nut crops because it generally produces a far superior plant than those produced from cuttings. Grafting allows the combination of a desirable high yielding scion with a vigorous seedling rootstock which results in increasing the general strength of the new plant. The rootstock may have other desirable characteristics such as disease resistance, tolerance to adverse soil conditions or may affect the nut quality, yield, earliness of bearing, and growth rate of the scion.

In light of these advantages, a survey of the literature was undertaken for grafting techniques that seemed to be applicable for the nursery propagation of jojoba. Two methods that appeared to have promise were the modified seed grafting technique (39) developed for camelias and chestnuts and the stone grafting technique of mangoes (8). In the modified seed grafting technique a recently germinated seedling was decapitated just above the cotyledons and a perpendicular slit made into the hypocotyl. The wedge shaped scion was then inserted into the slit and the graft tied. The stone grafting technique of mango differed in that the seedling was decapitated four centimeters above the cotyledons and a scion was either cleft or whip grafted onto the epicotyl.

In both techniques, the grafted seedlings were replanted in a potting medium and then covered with a polyethylene enclosed propagating frame, sometimes referred to as a Wardian case (22). The Wardian case promoted high temperature and humidity conditions which were conducive to good callus and graft formation.

These techniques have the advantage of requiring very little scion wood, and can be performed on young seedlings that demand very little greenhouse space and maintenance.

One of the foremost prerequisites in grafting is to bring the cambia of the scion and rootstock into close proximity. Recent anatomical survey of the stem (13) confirms earlier observations that jojoba has an anomalous secondary growth pattern which is characterized by the formation of successive independent extrafascicular cambia. An extrafascicular cambium typically is active only for a portion of a growing season. As one cambium area ceases activity, another is organized in the form of a complete ring or large arc through the dedifferentiation of cells in the peripheral conjunctive tissue. Therefore, it is assumed that actively growing new wood of approximately the same diameter as the young rootstock would increase the chance of bringing these highly meristematic regions (the most recently formed extrafascicular cambium and the dedifferentiating peripheral conjunctive tissue) into close proximity.

One of the main prerequisites of seed grafting is a vigorously growing rootstock, therefore, propagation by seed becomes of prime importance. For this, it is necessary to be familiar with the seed characteristics, its needs and limitations.

The main source of jojoba seed is from wild populations in the Sonoran Desert. Seed is usually harvested when fully mature and the seed capsule begins to dehisce, at which stage the seed capsule easily absisces and drops to the ground. Due to the nature of the shrub and the presence of rodents that collect and eat the seed, it is easily lost. To prevent this loss, the seed is sometimes harvested when the capsule is still green, although fully mature, containing a high amount of moisture and requiring drying before storage and planting (20,41,57).

Jojoba seed is produced in a trivacuolated capsule that can contain one, two or three seeds. Usually two of the embryos abort at an early age and one large seed fills the entire capsule. The majority of the fleshy tissue of the seed is cotyledon tissue with very little endosperm present. The micropylar end of the seed is slightly pointed and contains the embryo while the chalazal end is rather flattened and contains, primarily, cotyledon tissue (20,57,47).

Seed can be stored for up to a year without losing viability. If longer storage periods are required, the seed can be stored in air tight containers in a refrigerator for many years. Fresh seed has an average germination percentage of 90% while seed stored for 11 years in an open shed is reported to have 38% germination (21,41,54).

Ideal conditions for germination are darkness, a temperature of approximately 28°C and constant moisture. Temperatures below 14°C and above 34°C inhibit the rate and percentage of germination (15,37,38).

Soaking the seed prior to germination has been reported to stimulate germination. Some authors suggest soaking the seed overnight while others suggest 12 and 24 hours (20,43, 54). Seed scarification had no effect on germination (43). Seed with one cotyledon removed or the chalazal end of both cotyledons removed still germinated and produced normal plants (60).

Germination is hypogenous, with the radicle emerging two or three days after planting. The radicle grows at a rate of 2.5 cm per day for approximately 10 days then slows to 1 cm per day with the emergence of the epicotyl. The deep tap root of jojoba grows as deep as 30 meters and is one of its many adaptations to a dry desert environment (7,20,41,47,54,56).

The liquid wax stored in the parenchyma cells of the cotyledons is used as an energy source during germination and early growth (26,47). Wax content varies due to the genetic makeup of the seed, its size and the environmental conditions under which the seed is formed. Moisture stress during the early development of the seed hinders wax production (57,60). Therefore, it can be assumed that seed which is large and well developed during its early stages of growth will produce the most vigorous seedling, indicating further the need for good growing conditions, especially during the early part of the season.

The occurrence of fungal pathogens on the seeds and roots of jojoba have been reported. These diseases include Phythopthora, Fusarium, Pythium and Rhizoctonia (3,52). Recent evidence points out the lack of fungal proteinase inhibitors in the seed suggesting to the author that water-logged soil conditions should be avoided (50).

The importance of media should not be underestimated in developing propagating techniques. Under nursery conditions, jojoba is grown in a variety of soil and soilless mixes (20,54,59). One of the most important prerequisites in selecting a medium is that it be well drained and aerated since jojoba was slower growing under low soil oxygen conditions (46). Jojoba plants grown at 33°C were taller and accumulated more dry weight than at 21° and 27°C, showing that the temperature of the medium can also affect the growth of the plant.

The pH of a medium has been found to be important in that it affects the availability of nutrients to the growing plant. Although the optimal soil pH range for jojoba has not been determined, extensive pH measurements taken from jojoba popuplations in Mexico and the United States gave pH readings varying from 5 to 8 (58), suggesting that pH may not be overly critical in the culture of jojoba. Under greenhouse conditions, a neutral to slightly alkaline (7.0 to 8.0) pH was recommended for jojoba (54). The further importance of media pH will be discussed later.

Many types of containers, from tar paper cylinders to seedling trays, have been used to grow jojoba seedlings (20,54,59). An open-ended container set on a screen has been reported to be very useful. This type of container allows air pruning of the rapidly growing taproot with promotion of vigorous lateral root growth. Close-ended containers such as gallon or quart cans have been known to force the taproot into a spiralling growth pattern like a coil. This severely limits the growth of the plant when it is transplanted to the field (20,54,59).

Jojoba seedlings have also been grown in speedling trays (59). In this technique a wheat or barley seed was introduced into the medium with the jojoba seedling six weeks after planting. When the seedling of grain started to grow, its fibrous root system bound the medium tightly around the root system of the jojoba. The jojoba and wheat seedling were then easily lifted from the seedling tray and transplanted with minimal damage to the jojoba root system. Once transplanted, the wheat seedling was snipped off at the soil level.

Transplanting of seedlings into the field has given mixed results. Both high survival and mortality rates have been reported. Good results were obtained when care was taken to minimize damage to the fragile root system and an adequate amount of water was applied without causing oxygen deficient conditions in the soil (4,20,28,29,31,42, 44,45,54,59).

Jojoba seedlings, growing in containers have responded to fertilization treatments, especially N and P. Nutrient uptake was greatest when the soil temperature was maintained at 30°C (2).

Many of the greenhouse mixes used today are soilless. One widely used soilless medium is the Cornell Foliage Mix (12) which consists of a mixture of perlite, peat, and vermiculite, in the ratio of 1-2-1, respectively. The pH of the medium is quite acidic due to the high peat content, therefore a liming recommendation is made, but no mention of the resulting pH is given. Since jojoba has been reported to prefer a slightly alkaline greenhouse medium (20,54) which is above the range recommended for most plants (13), more lime may be needed.

Addition of lime to the medium will have many effects besides increasing pH and base saturation. More importantly, it will alter the availability and toxicity of many of the elements in the medium to the growing seedling (10,11,14, 23,30,32,34,35,44). A summary of these relationships for organic soils is shown in Figure 1. As noted by the authors, pH values between 5.0 and 5.8 correlated on the whole with the greatest availability of plant nutrients, which is 1 to 1.5 pH units lower than that generally considered to be most desirable for mineral soils (34). The chart was based on organic soils having at least 50 percent organic matter which is similar to that of the Cornell Foliage Mix.

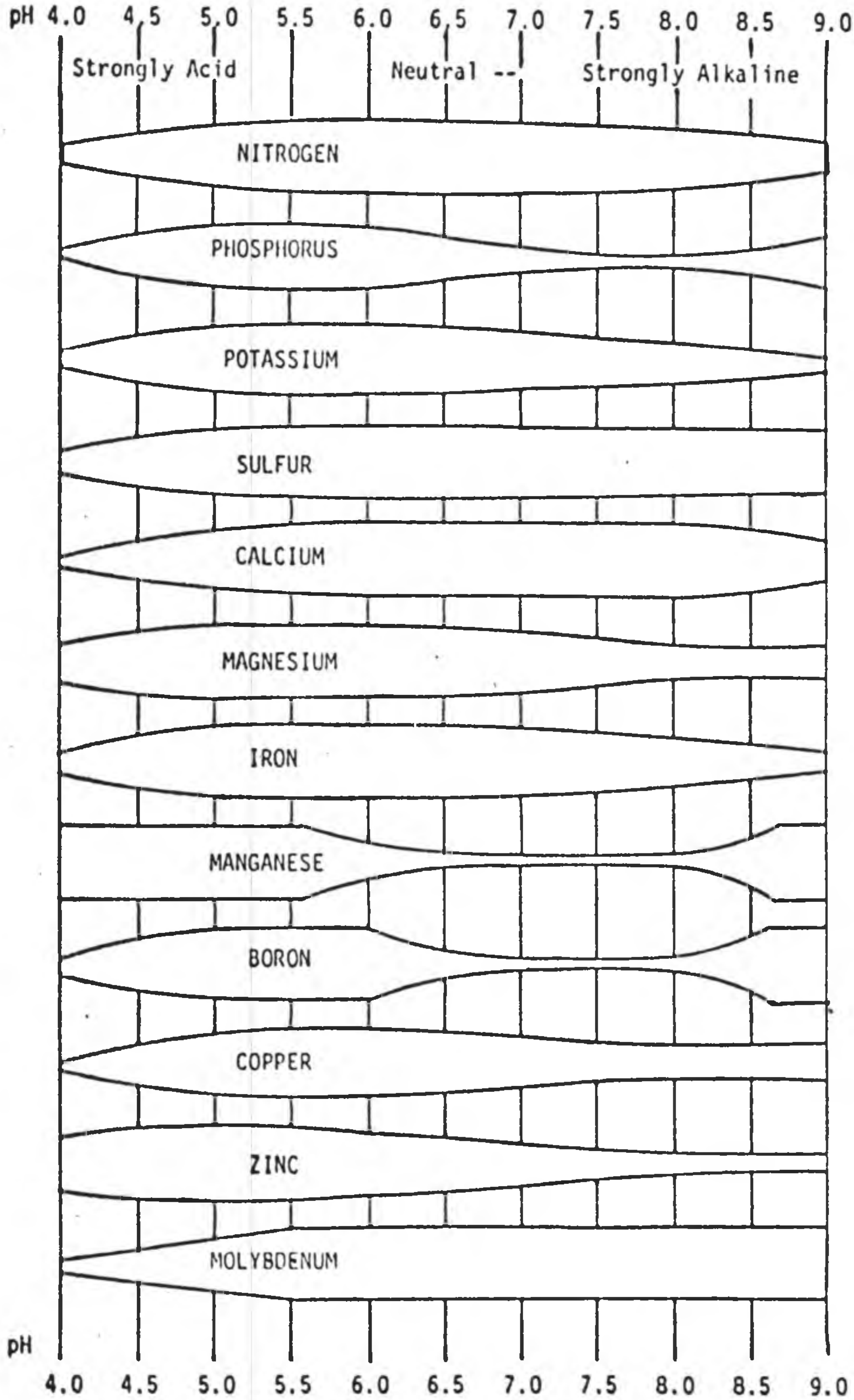

Figure 1. Influence of reaction on availability of plant nutrients (organic soils) (widest part of bar indicates maximum availability). (Redrawn from Lucas and Davis)

Liming in excess of this optimum range may cause the following detrimental effects (10,13,14,30,34,35):

1. Deficiencies of available iron, manganese, copper and zinc may be induced.
2. Phosphate availability may decrease because of the formation of complex insoluble calcium phosphates.
3. The uptake and utilization of boron may be hindered.
4. The uptake of potassium may be hindered due to the mass action effect of calcium.

II. MATERIALS AND METHODS

Liming Experiment

Media of perlite, Canadian sphagnum peat moss and vermiculite, in the proportion 1-2-1, respectively, were mixed in a 19 liter plastic container. Liming treatments of 0, 1, 2, 3, and 4 kg/m^3 calcium carbonate (85% at 200 mesh) were added to the dry mixture during preparation. The two-thirds full container was then sealed and shaken vigorously for one minute to insure uniform distribution of the lime throughout the medium. After mixing, the medium was wetted slightly and the planting containers filled. Between each mixing, the container was washed and dried.

Five wooden frames with 13 mm galvanized screening on the bottom were constructed; each to hold 72 rectangular potting tubes. The open ended white cardboard tubes, 38 x 38 x 203 mm were individually marked and filled with the respective treatment. Each wooden frame was a complete replicate of all five treatments completely randomized with 14 tubes (subsamples) per treatment. The two extra tubes per frame were filled with the medium but never planted. The wooden frames were randomly placed above the nursery bench on stilts and watered occasionally for three weeks to allow the pH of the medium to equilibrate.

On August 19th the tubes were individually seeded with randomly harvested jojoba seed from Arizona. Prior to planting, the seeds were surface sterilized in a 5 percent clorox solution for five minutes, washed, then soaked in water for four hours. After planting, a daily watering program was maintained to insure that the medium never became dry.

Two weeks after planting a weekly fertilizer program was initiated. Ten milliliters of a 1,200 ppm liquid feed fertilizer (Stern's Miracle Grow, 15-30-15 plus minor elements) was pipetted into each tube.

Three weeks after planting, tubes containing ungerminated seed were removed and replaced with seedlings of a similar treatment from replicate five, resulting in four complete replicates. Each replicate contained all five treatments with 14 individual plants per treatment.

On October 1st, two tubes per treatment per replicate were randomly selected to analyze the pH of the medium. The planting tube was discarded and the medium from around each plant was removed and placed in a plastic bag. The bags were then shaken vigorously before a sample was removed for testing. Approximately equal volumes of medium (35 ml) were placed in paper cups and stirred while distilled water was added to create a slurry. One hour later the slurry was stirred and the pH of the medium determined on a pH meter.

On December 15th, the stem of each seedling was removed at the cotyledon petioles and placed in a forced air oven for 36 hours at 70 before the dry weight was determined. The stem was completely defoliated and the length recorded. Tissue samples were prepared for analysis by combining the leaves of each plant by treatment within a replication.

Tissue analyses were made at the University of Hawaii Tissue and Soil Analysis Laboratory. Nitrogen analysis was by the Kjehdal method and the other nutrients by a vacuum x-ray fluorescent quantometer (17).

The pH of the medium was determined by the same method as previously described except three tubes per treatment per replicate were analyzed.

Grafting

Trial I

Seedlings were grown in the same manner as previously described except that the pH of the medium was left unchanged. Five weeks after seeding, 16 of the most vigorous seedlings were selected for grafting. In order to secure scion wood of approximately the same diameter as that of the rootstock, the diameter of the stem between the cotyledons and the first node was measured with calipers. This measurement (approximately 2 mm) was then used in selecting recently matured one or two node scion wood of approximately the same diameter. The rootstock was decapitated at this location in preparation for grafting (Figure 2). A grafting technique similar to the stone-grafting technique of mangoes was employed since earlier trials showed it to be

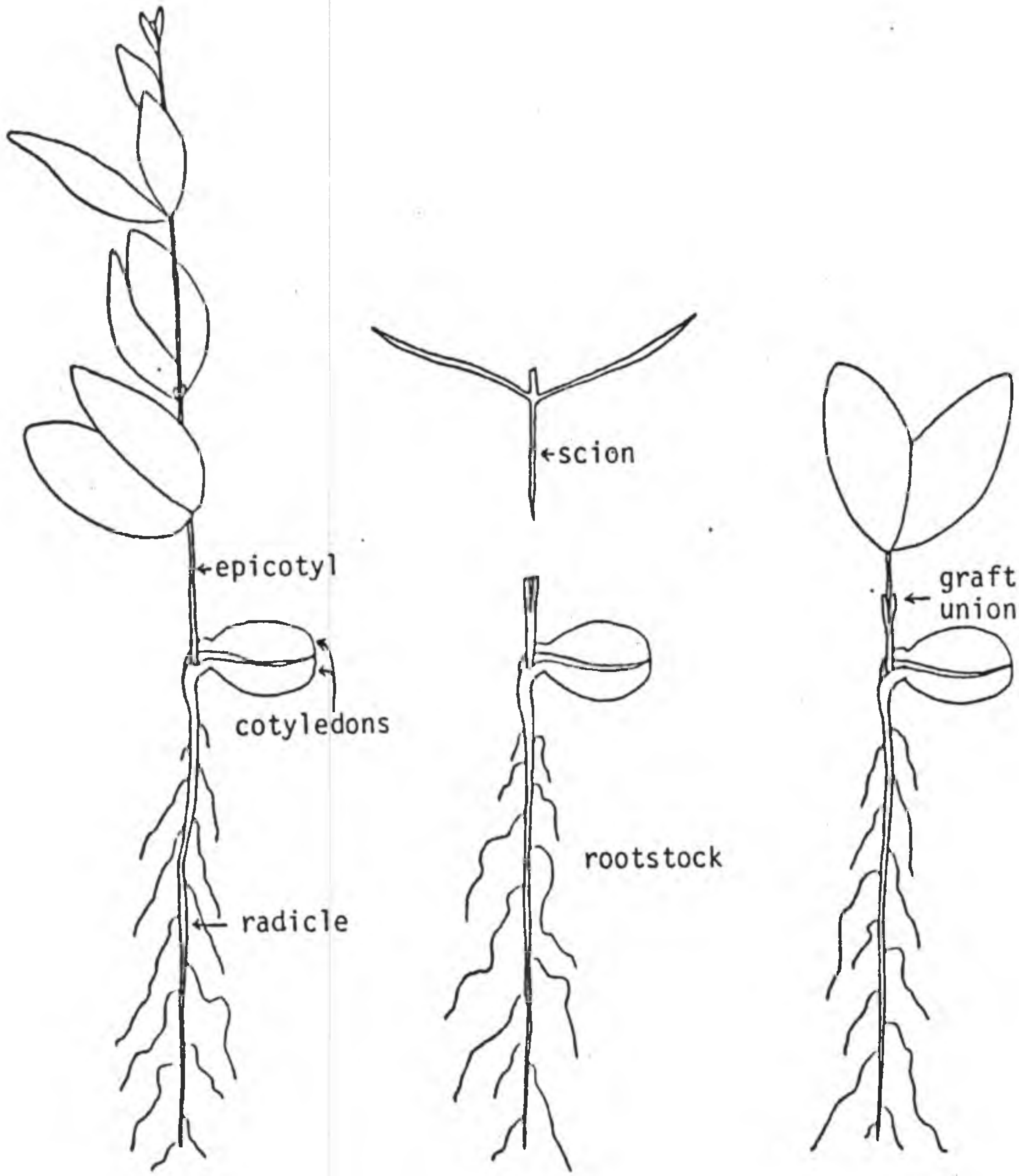

Figure 2. Grafting Technique. Left: seedling plant ready for grafting. Center: epicotyl cut radially, ready for insertion of the scion. Right: scion inserted.

better adapted to jojoba propagation than the modified seed grafting technique of camelias and chestnuts.

The basipital end of the scion was cut into the shape of a wedge with the aid of a triangular shaped wooden block having a 33 percent slope. Across the entire diameter of the rootstock, a radial cut was made and the scion inserted. A plastic grafting clip was used to hold the scion wood in place.

The grafted seedlings were held under high humidity in a Wardian case (22) under covered shade.

A slow climatization back to greenhouse temperatures and humidity was started ten days after grafting by making slits in the sides of the plastic covering of the Wardian case. Each day the slits were enlarged until the case was eventually removed two weeks after grafting. Once the Wardian case was removed the plants were moved from the covered shade into a small saran tent with 40 percent shade. At this time the watering and fertilization regimes were resumed.

Trials II and III

The following two trials were not conducted at the same time but are so similar that they will be presented together. They differ in the raising and handling of the rootstock prior to and during grafting.

In the second trial the rootstocks were raised in three plastic pots (15 cm in diameter and 11 cm tall), whereas in the third trial they were grown in a screened bottom planting box (25 x 25 x 15 mm). Both containers were filled with vermiculite and planted with pretreated seed. The seeds were evenly spaced in the containers with 10 seeds per pot and 40 seeds in the planting box.

Four weeks after planting, 20 rootstocks from each trial were removed from their medium and wedge-grafted in the same manner as previously described. The long spiraling taproot of the pot grown rootstocks was root pruned 6 cms below the cotyledons. It was not necessary to root prune the seedlings grown in the open bottom planting box. Once grafted and pruned the seedlings were planted in vermiculite filled plastic pots, then a plastic bag was slipped over the top of each pot and secured with a rubber band. The plastic bag was positioned so that it would not touch the grafted seedling while the grafts were healing under a saran tent of forty percent shade. Two weeks after grafting, a climatization program similar to the one described in trial I was started. The plants were moved into full sunlight one week later.

III. RESULTS

Liming Experiment

The mean concentration of each element in the jojoba leaves is presented in Table 1 along with concentration values considered adequate for most higher plants (49). On the whole, most of these values are equal to or exceed the adequate concentrations. Differences may be attributed to the plant type and age or the sampling and tissue analysis techniques.

The effect of liming on the pH of the medium is graphically represented in Figure 3. Note that at the higher liming rates, the increased lime does not significantly influence the pH of the medium.

Separation of means for only those elements and growth measurements that were shown to be significantly different in respect to treatment are presented in Table 2.

Dry weight accumulation was 32 percent greater in the control (pH 5.8) than in any of the other treatments. The general trend for the elements as the treatment level and media pH increased was a decrease in the phosphorus and potassium leaf concentrations and an increase in the calcium content. Graphic representations of the results are shown for dry weight, phosphorus, potassium and calcium in Figures 4, 5, 6 and 7, respectively. Correlation coefficients for the significant variables also supports this trend (Table 3).

Table 1. Mineral analysis of jojoba leaves* and internal concentrations considered adequate for most higher plants (49).

Element	Leaf Conc. (ppm)	Adequate Con. (ppm)
Nitrogen	13,000	15,000
Phosphorus	3,000	2,000
Potassium	23,000	10,000
Calcium	10,000	5,000
Magnesium	8,000	2,000
Sulphur	4,000	1,000
Aluminum	35	**
Manganese	151	50
Iron	70	100
Copper	9	6
Zinc	279	20

*Average leaf concentrations of elements over the liming treatments (0, 1, 2, 3, 4 kg/m^3 $CaCO_3$). Only phosporus, calcium and potassium leaf concentrations differed significantly as shown in Table 2.

**Not available.

Table 2. The effect of liming on: the pH of the medium; the top dry weight accumulation and mineral leaf concentrations* of jojoba seedlings growing in a soilless medium.

$CaCO_3$ Treatment (g/1)	pH	Dry Weight (g)	Nutrient Composition (%)		
			CA	P	K
0	5.8d[y]	1.40a	0.932b	0.336a	2.449a
1	6.2c	1.02b	0.897b	0.345a	2.522a
2	6.9b	1.09b	1.030ab	0.294b	2.120b
3	7.7a	1.04b	1.125a	0.249c	2.048b
4	7.8a	1.08b	1.142a	0.284bc	2.146b

*Only those leaf concentrations with a significant mean separation are presented.

[y]Mean separation in columns by Bayesian LSD 5 percent.

Table 3. Correlation coefficient matrix of $CaCO_3$ liming treatments, pH of the medium, calcium, phosphorus, potassium leaf concentrations and top dry weight accumulation of jojoba seedlings.

	Treatment	pH	Calcium	Phosphorus	Potassium	Dry Weight
Treatment	--	0.986**	0.696**	-0.620**	-0.612**	-0.548*
pH	0.986**	--	0.677**	-0.637**	-0.637**	-0.625**
Calcium	0.696**	0.677**	--	-0.699**	-0.579**	$-0.275^{n.s.}$
Phosphorus	-0.620**	-0.637**	-0.699**	--	0.774**	$0.310^{n.s.}$
Potassium	-0.612**	-0.637**	-0.579**	0.774**	--	$0.282^{n.s.}$
Dry Weight	-0.548*	-0.625**	$-0.275^{n.s.}$	$0.310^{n.s.}$	$0.282^{n.s.}$	--

*Significant at the 5 percent level.

**Significant at the 1 percent level.

$^{n.s.}$Non-significant.

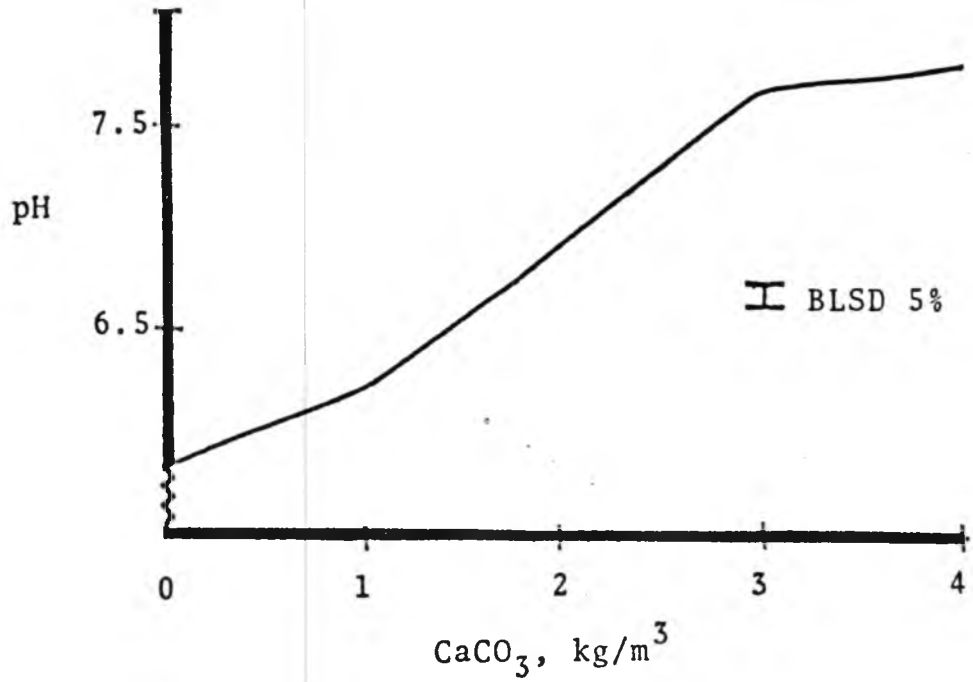

Figure 3. Effect of liming on the pH of the medium perlite, peat, vermiculite, 1-2-1, mixed 7/30; seeded 8/19; pH tested; 10/1 and 12/16.

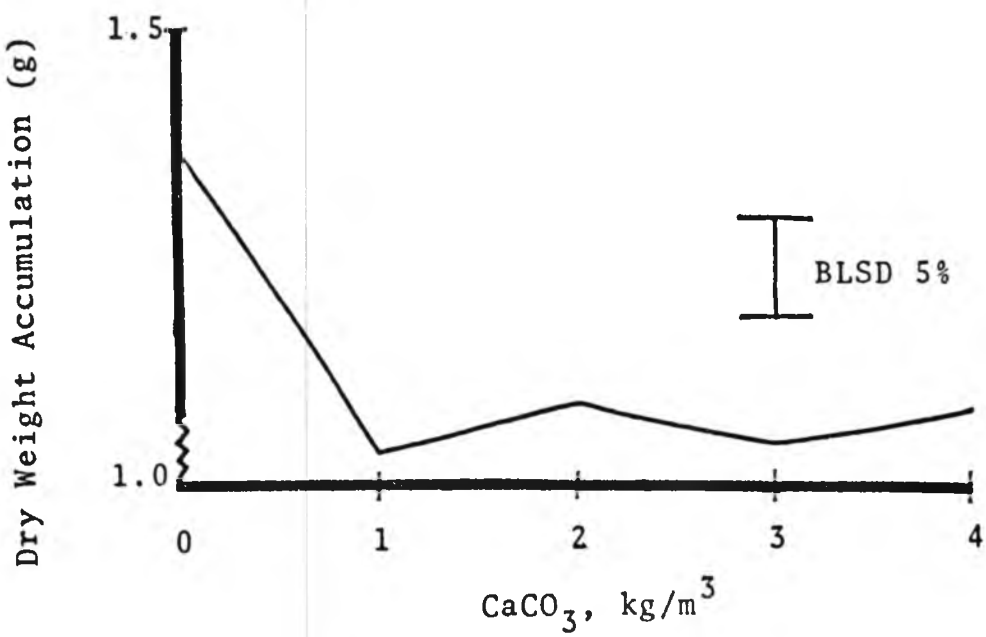

Figure 4. Effect of liming on the top dry weight accumulation of jojoba seedlings growing in a soilless medium.

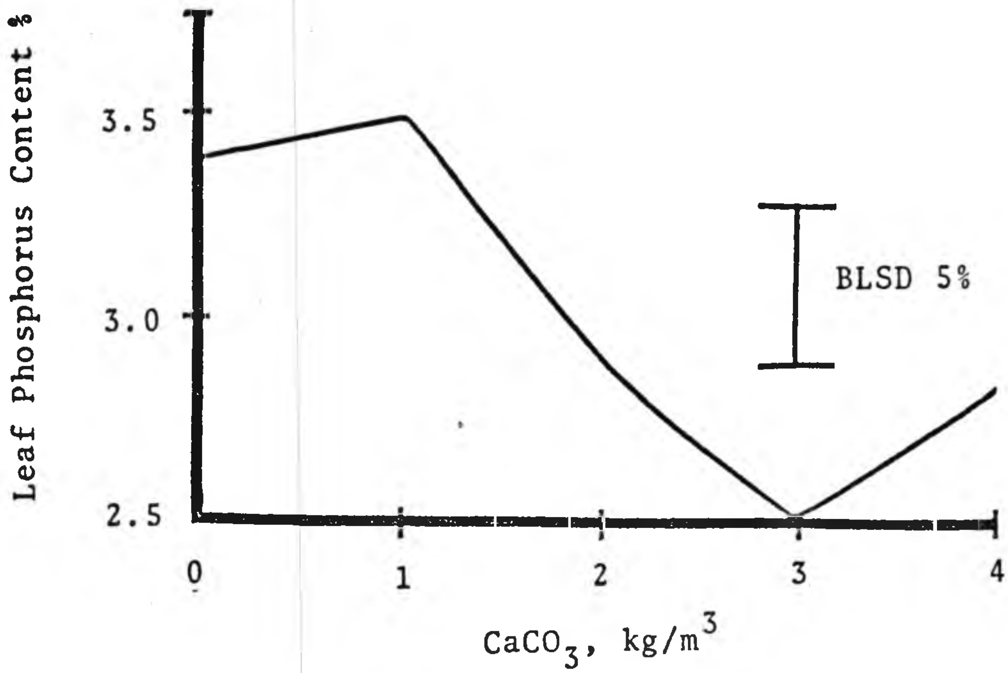

Figure 5. Effect of liming on the phosphorus content of the jojoba leaf.

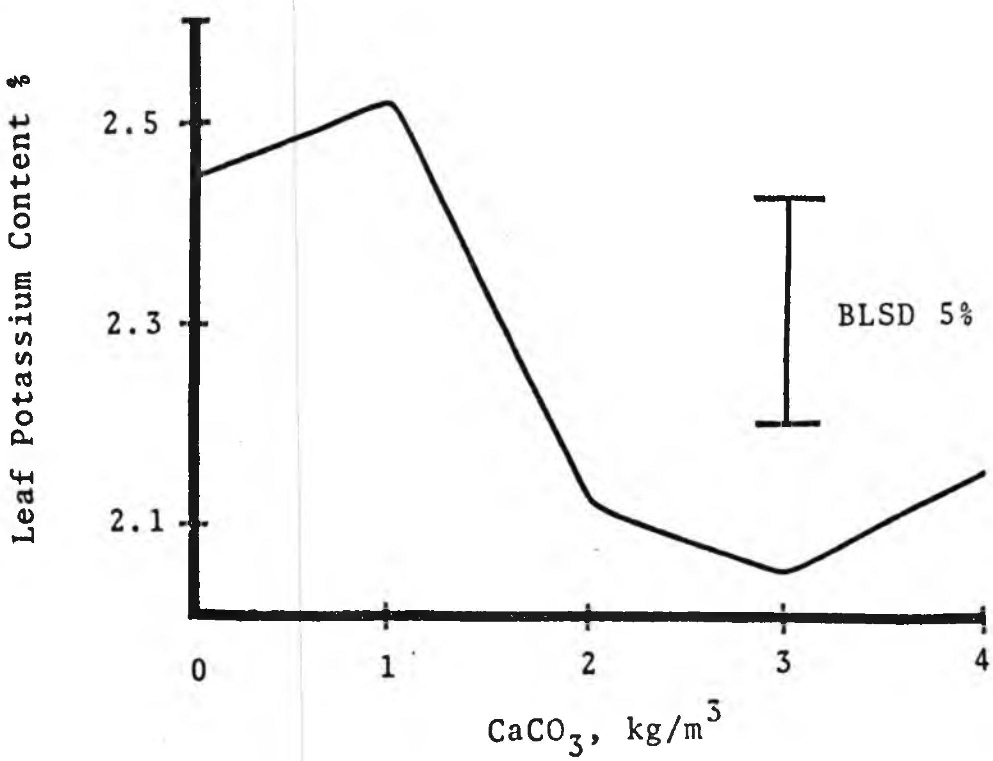

Figure 6. Effect of liming on the potassium content of the jojoba leaf.

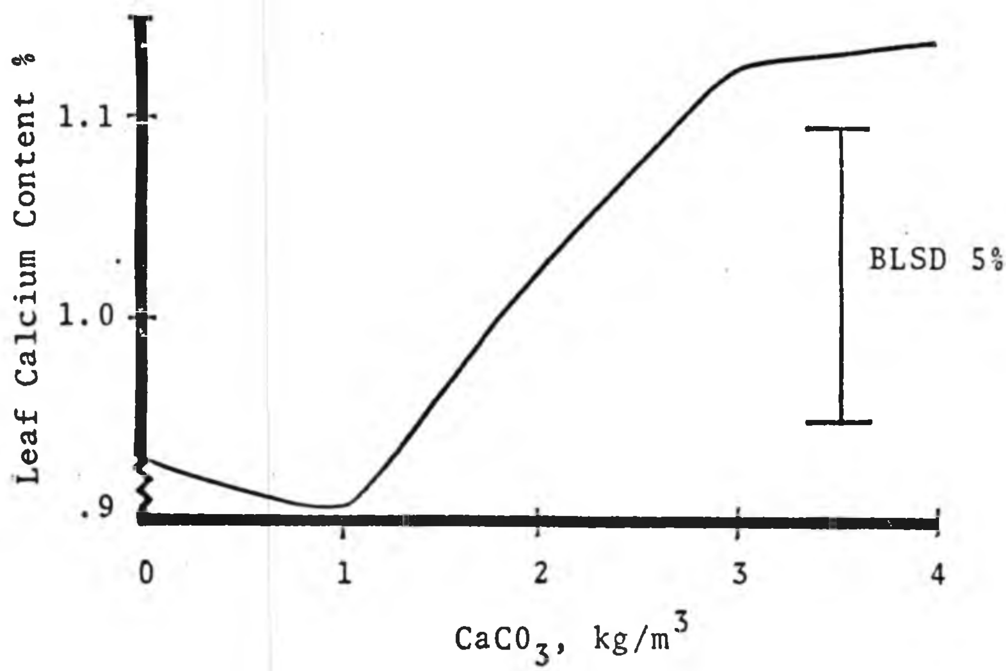

Figure 7. Effect of liming on the calcium content of the jojoba leaf.

<u>Grafting Trials I, II and III</u>

Two to four weeks after grafting, axillary buds of the scions started to grow. In some cases both opposed buds at a node started to grow whereas in other cases only one shoot arose. If both shoots started growing, one was removed. Shoots arising from the axillary buds of the cotyledons started to grow on approximately 30 percent of the rootstocks and were removed immediately. On one occasion a second shoot had to be removed from the area near the cotyledon petioles. Water soaked lesions on the cotyledons of the seed became noticeable while the plants were under the high temperature and humidity conditions of the Wardian case. In most cases the cotyledons completely rotted away after showing these symptoms. This problem was greatest in Trial I with the organic matter mix and occurred infrequently in the other two trials with vermiculite. Similar symptoms and results have been observed in non-grafted seedlings.

Six weeks after grafting, the percentage of successful grafts were tabulated (Table 4). At this time the grafted seedlings were repotted and the root systems surveyed. All the grafted seedlings except for two in Trial II survived the transplanting shock.

The mechanically pruned spiralling taproot of Trial II produced a very fibrous root system from the proximal end of the cut taproot. This root system looked almost adventitious in nature, similar to that produced by a cutting.

The air pruned taproots of Trial II and III produced a more branched lateral rootsystem that arose along the whole length of the taproot. In some cases the majority of the branching occurred near the end of the taproot. This was especially evident with the long taproot of the tube grown plants.

Table 4. Summary of grafting results on jojoba

Trial	Procedure	Taproot Pruning	% Success*
I	Grafted in Place	Air Pruned	85
II	Bench Grafted	Mechanically Pruned	70
III	Bench Grafted	Air Pruned	80

*Trials I, II and III - 16, 20, 20 seedlings, respectively.

IV. DISCUSSION

Liming Experiment

The effects of liming on a medium are numerous and very complicated. Many intercorrelations between liming, pH of the medium as well as its effect on nutrient availability and uptake by the plant were exemplified in this experiment whereas others were not.

A positive correlation between the pH of the medium and the increased calcium carbonate application was shown graphically in Figure 3. Note that the pH of the medium changed very little at the higher liming rates implying a base saturated medium.

Another noticeable feature was the absense of pH change from the first to second sampling, ten weeks apart, suggesting that the pH of the medium had equilibrated fully by the first sampling and that very little leaching of $CaCO_3$ occurred between the two sampling dates. Assuming that the Cornell Foliage Mix has similar properties to that of an organic soil of at least 50 percent organic matter, then the optimum pH range of greatest nutrient availability would correlate most closely with the zero liming treatment, pH 5.8, and that overliming in excess of this may cause several detrimental effects as has been shown in the case of phosphorus and potassium uptake by the jojoba plant.

The availability of phosphorus in the medium has been shown to be affected by the kind of phosphate ion present and the solubility of other minerals that combine with phosphorus to form insoluble compounds, which, in turn, has been determined to be affected by the pH of the medium (10,13,14, 34,35,49). Under highly acid conditions only the $H_2PO_4^-$ ions dominated, whereas with increasing pH, first the $HPO_4^=$ ions, and finally under very alkaline conditions, the PO_4^{3-} ions were the most abundant (10,13,34). Since phosphorus has been shown to be absorbed by the plant primarily as $H_2PO_4^-$, and less rapidly as $HPO_4^=$, a slightly acid to moderately acid soil is preferred (10,13,34,39,49).

The availability of phosphorous in mineral soils has also been shown to be affected by the presence of soluble iron and aluminum under acid conditions or calcium at high pH values through the formation of insoluble compounds (10,13,14,34,35). In the Cornell Foliage Mix, the presence of iron and aluminum were reported to be very low in comparison to mineral soils, therefore, the complication of these ions forming insoluble compounds was not expected to be as great (14). The presence of a high calcium content at the higher pH values would promote the formation of insoluble calcium phosphates, hence the reduction in the amount of phosphorus accumulated in the jojoba leaves. These interactions hopefully can be used to explain the decrease in phosphorus content in the jojoba leaves with the increased pH and liming treatment (Figure 5).

The correlation between the decrease in potassium accumulation in the leaf with increasing liming treatment (Figure 6) has been generally recognized as a problem of ion competition rather than fixation. The mass action effect of the Ca^{++} ion over the K^{+} ion at higher liming rates decreases the absorption of potassium into the plant (10,13, 14,34,35).

In surveying the dry weight accumulation of the plant in respect to treatment (Figure 4), it was found that the plants grown under the no lime treatment accumulated significantly more dry weight than plants grown under any other treatments; however, there was no significant decrease in dry weight with increasing treatment after this first significant drop. Since all of the nutrients tested occurred in approximately the same leaf concentrations in both of these treatments, including phosphorus, potassium, and calcium, it may be assumed that some other factor caused this rapid decrease in the top dry matter accumulation of the jojoba seedlings. One such factor is boron since its availability decreases rapidly with an increase in pH above the optimum range (Figure 1).

The last significant correlation was between the calcium content of the leaf with the higher liming rates. This is probably a case of luxury consumption since the calcium level in the medium increased considerably with liming.

Under the conditions of this study the results suggest that jojoba seedlings prefer a pH range similar to that of most plants, and that the media should not be limed in excess of this range to promote alkalinity. Recommendations that the greenhouse media be slightly alkaline (54) may have stemmed from the assumption that this is one of the predominant soil characteristics of many of the native jojoba populations. The fact that jojoba is found growing in these areas may not be a direct response to soil pH but rather to the arid climatic environment to which jojoba is well adapted, which incidentally encourages the development of alkaline soils (2). Other beneficial factors associated with alkaline soils, that may attribute to jojoba's reported preference to these soils, but were not brought out by this experiment were: 1. the removal or neutralization of toxic compounds of either an organic or inorganic nature. 2. the retardation of plant diseases. 3. an encouragement of micro-organic activities favorable in a nutritive way (13).

Grafting Trials

The results of three trials showed that the seed grafting technique employed was a very feasible method for the nursery propagation of jojoba and with a little practice can be easily performed. Each trial had a different method of handling the rootstocks; therefore, the advantages and disadvantages of each technique will be discussed.

The rootstock seedlings of trial I were grafted within the same tube in which they were seeded whereas the seedlings of trial II and III were removed from the media, bench grafted and then repotted. The seedlings of trial I were easier to handle in that they did not need repotting after grafting nor were they susceptible to transplant shock. They were harder to graft due to the awkwardness of the tube which often hindered the proper placement of the grafting clip. Possibly a removeable collar on the top of the tube could be implemented to facilitate grafting.

Two types of rootsystems were promoted by the root pruning techniques used in the different trials. In trials I and III the air pruned taproot formed a rootsystem with lateral branches from the main taproot, whereas in trial II the mechanically pruned taproot formed a fibrous adventious rootsystem similar to that of a cutting. Since one of the advantages of seed grafting is the incorporation of a vigorous seedling rootstock with a selected clone, then the fibrous adventitious rootsystem would not be as desirable, and might be more easily produced on a rooted stem cutting.

Occurrence of seed pathogens seemed to be more prevalent in trial I with a peat containing medium than in the other two trials of solely vermiculite. This may have been due to the presence of disease causing organisms in the peat or the high water holding capacity of the peat medium which favored the growth of introduced pathogens. To prevent this, possibly a protective seed treatment at planting or prior to grafting, alone or in combination with soil drench near to the surface of the medium, may be effective. Also, reduction of the humidity within the Wardian case may prove useful if it does not severly limit callus formation at the graft union.

Further work is needed to compare the advantages of grafted seedlings with cutting propagated plants under different cultural systems. A fibrous cutting rootsystem may work well for an irrigated farming crop but not for a rainfed crop where drought tolerance is essential. Other advantages to grafted seedlings are as follows: conservation of scion wood, possible use of disease resistant or salt tolerant rootstock, and propagation of superior clones that do not root easily. Hopefully the grafted seedling technique used will be tested under a variety of different situations and become useful somewhere in the upcoming industry.

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